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Multi-mode Fiber Coarse WDM Grating Router Using Broadband Add/Drop Filters for Wavelength Re-Use

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We demonstrate a grating-router with 37nm channel spacing and 6nm FWHM in the 800-900nm range for WDM over multimode fiber. Broadband thin-film add/drop filters provide wavelength re-use enabling NxN fully non-blocking interconnection with N wavelengths.

Introduction

For single mode fiber (SMF) applications the arrayed waveguide grating router (AWG) provides passive wavelength routing with spectral channels being used more than once in the routing table to achieve full NxN interconnection with only N wavelengths[1]. AWGs cannot be used with MMF due to the excessive losses in coupling from MMF to single mode waveguides. We report the development of a wavelength router (NxN wavelength multiplexer) for use in MMF based optical networks. The device uses a blazed diffraction grating and broadband add/drop filters to provide wavelength re-use thus enabling fully non-blocking NxN interconnection with only N wavelengths. Initial experimental results using 3 inputs and 3 outputs are presented.

Device Configuration

Figure 1 shows the experimental setup. In this figure, the inputs A, B, and C are mapped to outputs 1, 2, 3, 1*, and 2*, which are subsequently combined with add/drop filters to produce the final 3 outputs X, Y, and Z. Wavelength routing was demonstrated using 3 wavelength channels: 827, 864, and 900 nm. Graded index (GRIN) 62.5/125 μm MMF inputs and outputs were terminated in an MT ferrule to provide a fiber to fiber pitch of 250 μm. Three fibers were illuminated with white light from a tungsten lamp. A lens was used to collimate the incident light from the inputs and focus the diffracted light from the grating. Based on the fiber pitch and spectral channel spacing a linear dispersion of $\Delta x/\Delta\lambda = 250/35 = 7.143$ μm/nm was required in the focal plane of the lens. The linear dispersion of a lens and grating combination used in the Littrow configuration is given by: $\Delta x/\Delta\lambda = 2f\tan(\theta)/\lambda$ Where f is the focal length of the lens, and θ is the blaze angle of the grating. This equation is valid for wavelengths near the blaze wavelength. The diffraction grating used in this demonstration had a groove density of 400 lines/mm, blaze angle of 9.962 degrees (blaze wavelength = 845 nm for Littrow mounting), and was gold coated for high reflectivity. Based on the grating parameters, a lens with a focal length of 16mm was used to expand and focus the light to and from the fibers. By matching the linear dispersion of the lens and grating combination to the fiber pitch and spectral channel spacing, adjacent spectral channels from a single input are focused to adjacent output fibers. For example, input A, sends λ = 830, 865, and 900 nm to outputs 1, 2, and 3 respectively. Furthermore, by spacing the input fibers with the same pitch as the outputs, adjacent inputs send adjacent spectral channels to the same output. Thus, output 3 receives λ = 900, 865, and 830 nm from inputs A, B, and C respectively. For this device, in general, N inputs produce 2N-1 outputs, one of which has all N wavelengths properly routed and the rest of the outputs forming N-1 pairs of complementary beams. For

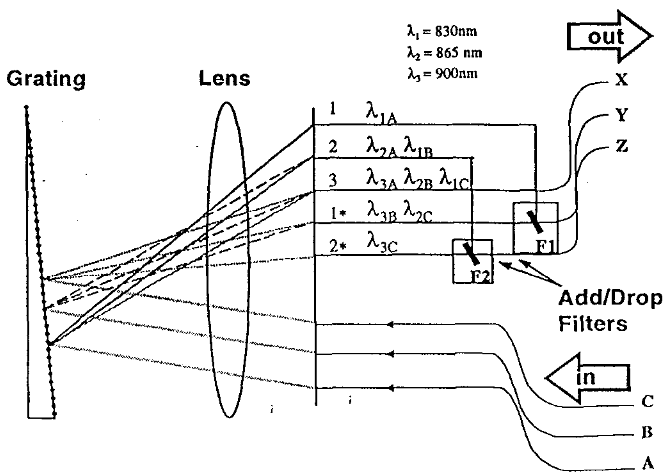

Figure 1. Coarse WDM Router Configuration

example, output 1 only receives $\lambda = 830$ nm, while output 1* receives $\lambda = 865$ and 900 nm. By combining these pairs of complementary beams, the full routing function is accomplished. Although 2x1 couplers could be used to combine the beam pairs, it is well known that this type of beam combining incurs a 3dB penalty [2]. In order to circumvent this penalty, we used two add/drop filters with different passbands to re-combine the two pairs of complementary output beams. In this application, two inputs are multiplexed onto a single output, one input being reflected by the filter and the other being transmitted through the filter.

Experimental Results

Figure 2 shows the output spectra from the three outputs (labeled X, Y, and Z in fig. 1), after beam recombination. Each output channel contains all three spectral channels. Although not apparent from this figure, each spectral channel in each output spectrum originates from a different input fiber. In this initial demonstration the channels had a FWHM of 6 nm. The average insertion loss of the device was 8.7 dB with a standard deviation of 0.81. Optimizing all of the system components will significantly reduce the insertion loss. For example, the add/drop filters were originally developed for another application and exhibit uncharacteristically high insertion losses, upto a maximum of 4.2 db, for the spectral channels of this experiment. These type of filters are reported to exhibit average insertion losses of 1 to 1.5 dB when optimized for the wavelengths of interest [3]. Furthermore, the maximum grating efficiency was 87 % (0.6 dB loss). Finally, the maximum insertion loss of 14.7 dB corresponds to the spectral channel that subtends the largest angle from input to output, travelling from input A to output 1 on figure 1. This light path experiences very high loss due to vignetting as confirmed by ray tracing. By replacing the lens in the system with a larger diameter 37.5 mm f/1.1 camera lens the problem of vignetting was eliminated, however, the increased focal length resulted in a linear dispersion of 20.8 μm/nm. The new lens supported spectral channel spacings of 12nm rather than the 37 nm required by the available add/drop filters. Although a full system demonstration was not possible, the average insertion loss of the lens and grating combination was reduced to 5 dB. Ultimately, we believe that a device exhibiting insertion losses of 3 to 4 dB per channel will be attainable.

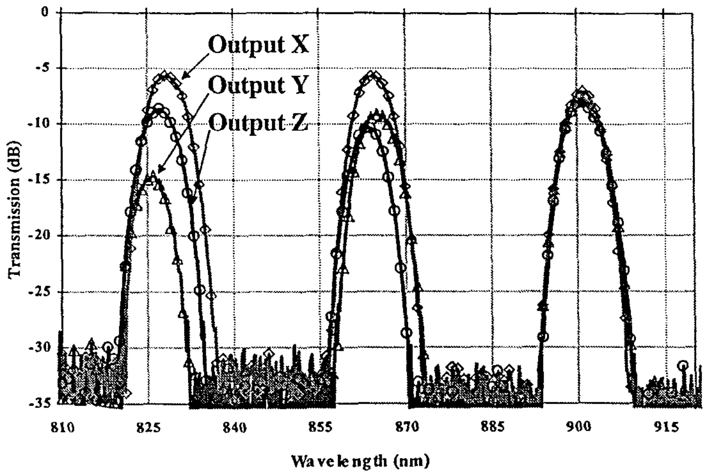

Figure 2. Router Output spectra

Summary

A MMF compatible coarse WDM wavelength router was demonstrated using a diffraction grating and broad-band add/drop filters to achieve wavelength re-use. The scalability of this device to higher channel counts is ultimately limited by the requirements on the lens, the fact that N-1 filter modules are needed to fully route N wavelengths, and the spatial fill factor of the input/output fiber arrays. The device provides a new tool for WDM over MMF. Furthermore, this design enables a bit-parallel wavelength router by using multiple sets of inputs and outputs. Coupled with multi-wavelength transmitter and receiver arrays such a device will provide high throughput, low latency optical interconnects suitable for massively parallel processing applications.

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